A Study on the Use of a New Risk Metric for TI-RIPB Safety Classification

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1. Introduction

Recently in the United States, new non-light water reactors (non-LWRs or NLWRs) can be licensed using the "Technology-Inclusive, Risk-Informed, and Performance-Based" (TI-RIPB) Method or the "Licensing Modernization Program" (LMP), which are supported by NRC regulations [1] and industry guidelines such as NEI [2]. The TI-RIPB method uses an F-C target, as shown in Fig. 1, rather than the "core damage frequency" (CDF) approach applied to LWRs, because the CDF concept cannot be used for certain NLWRs—such as Molten Salt Reactors (MSRs) and High Temperature Gas Cooled Reactors (HTGRs)—where it does not apply.

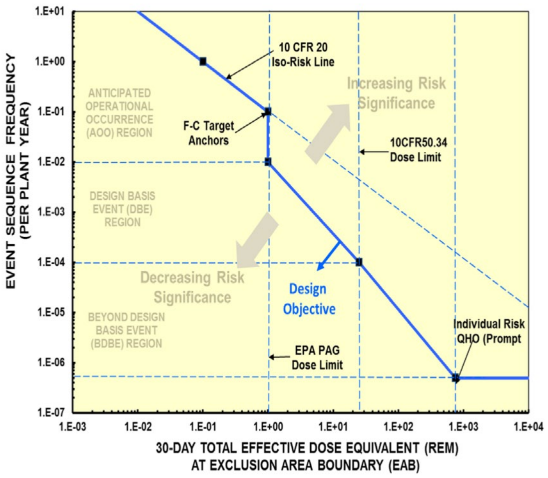

Fig. 1. Frequency-Consequence Target

The safety classification of Structures, Systems, and Components (SSCs) for NLWRs can be performed using the TI-RIPB method with the F-C curve. Consequently, many NLWRs can classify SSCs as "Safety-Related (SR)," "Non-Safety-Related with Special Treatment (NSRST)," or "Non-Safety-Related with No Special Treatment (NST)" using this curve.

In NEI 18-04 [2], which introduced the TI-RIPB methodology, a risk metric called "total risk" was also introduced as follows:

$$'total\ risk' = \sum_i f_i * C_i \qquad Eq.(1)$$

where, f_i = frequency,
c_i = consequence
i = licensing based events

However, no illustrative explanation exists for how to use this risk metric in the TI-RIPB methodology. Furthermore, there is no evidence that it has been widely applied in LMP reports [3] or other TI-RIPB frameworks. This paper introduces when and how the new "total risk" metric can be employed.

2. Methods

2.1 Xe-100 SSC Safety Classification

Risk-significant SSCs are those that prevent or mitigate any Licensing Basis Event (LBE) from exceeding the F-C Target. NSRST refers to non-safety-related SSCs that (1) perform risk-significant functions, or (2) require special treatment for defense-in-depth (DID) adequacy.

However, if the frequencies of LBEs do not lie within 1% of the F-C Target as shown in Fig. 2, it is unlikely that the SSCs associated with those LBEs would be classified as NSRST. The only remaining NSRST possibility is that they may be required from a DID adequacy perspective.

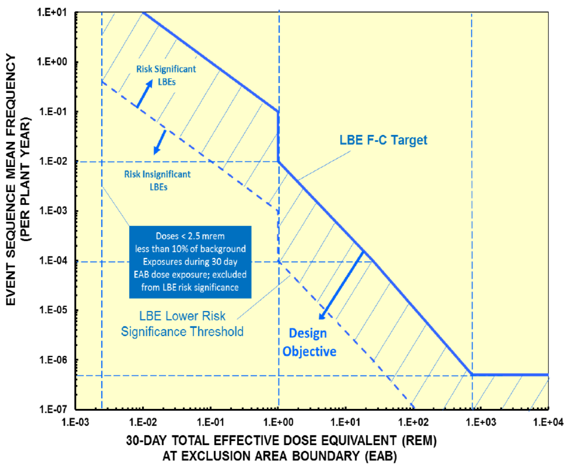

Fig. 2. Use of the F-C Target to Define Risk-Significant LBEs

The frequencies of Xe-100 LBEs lie far from the F-C Target, as shown in Fig. 3 [3], likely because the radionuclide release from TRISO fuel is very small. Therefore, there are no NSRST SSCs in the Xe-100 from a risk-significant perspective.

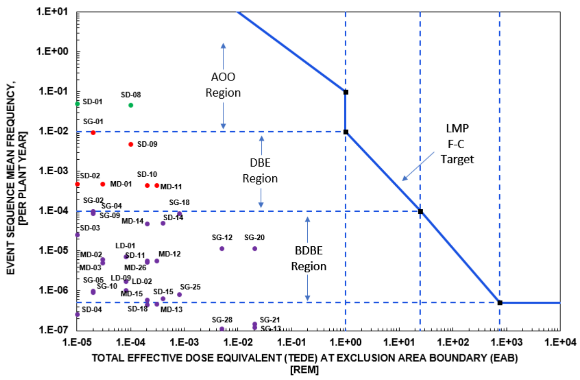

Fig. 3. Xe-100 Risk Comparison to F-C Target [3]

In this case, the following method, which uses the importance measure of a new risk metric 'total risk', is recommended.

2.2 Importance Measure of a 'Total Risk' Metric

The new "total risk" metric is defined in Eq. (1). To illustrate its usefulness, consider a simple plant model with two initiating events (e.g., %LL, %SL) and three systems (e.g., SYS_A, SYS_B, HPSI).

Let's assume that three event sequences (LBE_{LL2}, LBE_{LL3}, LBE_{SL2}) are derived with the event trees as shown in Fig. 4 ~ 5. The HPSI system is shown in Fig. 6.

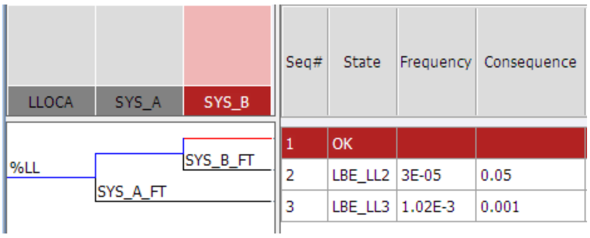

Fig. 4. LL Event Tree

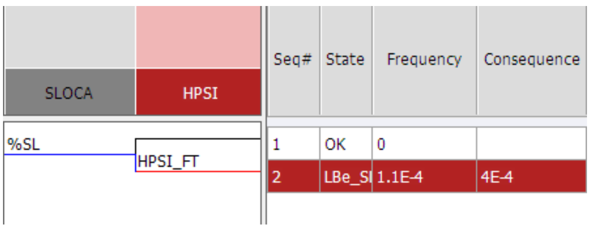

Fig. 5. SL Event Tree

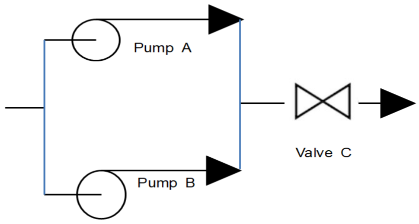

Fig. 6 The HPSI system

Also, the followings are assumed:

- *minimal cutsets SYS_A = {X, YZ, QY}*
  SYS_B = {XY, QZ, QR}
- *failure rates of X, Y, Z, Q, R, A, B are 0.01,*
- *failure rate of C is 0.001*
- *%SL = 0.1 /yr*
- *%LL = 0.1 /yr*
- *Pump A, B has 100% capacity, respectively.*

Then,

$$CDF = \%LL(X+YZ+QY+QZ+QR) + \%SL*(A*B+C)$$
$$= 0.00115\ /yr \qquad Eq.\ (2)$$

With CDF risk metric, RAW (risk achievement worth) of SSCs can be achieved as shown in Table 1.

Table 1. RAWs under the CDF Metric

SSC	Failure rate	RAW	Ranking
X	0.01	87.087	**2**
C	0.001	87.87	**1**
Q	0.01	3.583	**3**
Y	0.01	2.722	**4**
Z	0.01	2.722	**5**
A	0.01	1.861	6
B	0.01	1.861	7
R	0.01	1.861	8

Also, a new risk metric,

$$\text{'Total Risk'} = freq(LBE\_{LL2})*C_{LL2} + freq(LBE\_{LL3})*C_{LL3} + freq(LBE\_{SL2})*C_{SL}$$
$$= \%LL(XY+QZ+QR) * 0.05 + \%LL(X+YZ+QY) * 0.001 + \%SL*(AB+C) * 0.004$$
$$= 2.96E\text{-}06\ (rem/yr) \qquad Eq.\ (3)$$

where, consequences of LBE_{LL2}, LBE_{LL3}, LBE_{SL2} are assumed as $C_{LL2} = 0.05$, $C_{LL3} = 0.001$, $C_{SL2} = 0.004$, respectively.

It is assumed that the consequences of the three event sequences (LBE_$_{LL2}$, LBE_$_{LL3,}$ *LBE_$_{SL2}$*) are small, similar to all Xe-100 consequences, and lie far from the F-C Target, as shown in Fig. 2.

Using the 'total risk' metric, the RAW of SSCs can be obtained as shown in Table 2. As can be seen, the RAW ranking in Table 2 is similar to that in Table 1. Because the three consequences are small and their differences are not significant, the RAW ranking of SSCs with respect to CDF and to 'total risk' is similar.

Table 2. RAWs under the 'Total Risk' Metric

SSC	*Failure Rate*	*RAW*	*Ranking*
X	*0.01*	51	***2***
C	*0.001*	*136*	***1***
Q	*0.01*	*35*	***3***
Y	*0.01*	*18.4*	***4***
Z	*0.01*	*18.1*	***5***
A	*0.01*	*2*	*7*
B	*0.01*	*2*	*8*
R	*0.01*	*17,7*	*6*

In the Xe-100 design, it is understandable that NSRST cannot be decided using the F-C Target because the frequencies of LBEs lie far from that target., i.e., there is no SSC to perform a risk significant function [4]. Although, NSRST could be determined solely based on DID adequacy, in this situation, SSCs with a high RAW ranking under the 'total risk' metric can be recommended as NSRST SSCs. That classification is similar to RISC-2 ("non-safety-related but safety-significant SSCs") under 10 CFR 50.69 [5].

Of course, SSCs related to passive systems could also qualify as NSRST under RTNSS [6].

2.3 Boolean Reduction Issue

In Eq. (2), the Boolean expression 'X + XY' can be reduced to 'X.' This reduction is typically performed as a 'Del Term' operation in PSA quantification software. However, in Eq. (3), the expression 'XY * 0.05 + X * 0.001' cannot be simplified further.

3. Conclusions

The usefulness of a new risk metric, 'total risk,' is introduced. The corresponding RAW values could be helpful in classifying SSCs for NSRST in HTGRs, where LBE consequences are very small and lie far from the F-C Target. In such cases, SSCs with a high RAW ranking under the "total risk" metric may be recommended as NSRST SSCs, analogous to how "non-safety-related SSCs" with a high RAW (with respect to CDF) are categorized as RISC-2 under 10 CFR 50.69.

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REFERENCES

[1] NRC, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors", Regulatory Guide 1.233, Rev. 0, June 2020.

[2] NEI 18-04, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development", Rev. 1, Aug. 2019

[3] LMP Report for X-energy Xe-100, TICAP Tabletop Exercise Report, Technology Inclusive Content of Application Project for Non-Light Water Reactors, SC-16166-201 Rev 0, Aug. 2021

[4] ACRS, Official Transcript of Proceedings, X-Energy Xe-100 Design-Centered Subcommittee Aug 2024, Page 48

[5] NEI 00-04 (Rev 0) 10 CFR 50.69 SSC Categorization Guideline, July 2005.

[6] U.S. NRC Staff's Feedback and Observations Regarding ARC Clean Technology White Paper "Regulatory Treatment of Non-Safety Systems (RTNSS)", April 2023, ML23094A291